REPORT DOCUMENTATION PAGE Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for remaintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this bur				
Public reporting burden for this collection of informaintaining the data needed, and completing and	mation is estimated to average 1 hour per response I reviewing this collection of information. Send con	e, including the time for re AFKL nments regarding this bur		ling
eugagetions for reducing this hurden to Washingt	ton Headquarters Services, Directorate for Informat get, Paperwork Reduction Project (0704-0188), Wa	tion Operations and Repo	0597	
1. AGENCY USE ONLY (Leave	2. REPORT DATE	3. REPORT TYPL	enort 9/1/99-2/28/01	
blank) 4. TITLE AND SUBTITLE	10/02/01	Final Lechnical Re	5. FUNDING NUMBERS	
4. TITLE AND SUBTILLE			PE-61103D	
(II) Commutations of Drop	1st/Elaw Interactions in Spra	13.70	PR-3484	
(U) Computations of Droplet/Flow Interactions in Sprays		SA-WS		
6. AUTHOR(S)			F49620-00-1-0124	
			F49620-97-1-0525	
Gretar Tryggvason				
7. PERFORMING ORGANIZATION I	NAME(S) AND ADDRESS(ES)		8. PERFORMING ORGANIZATION	
77 ' ' C36' 1'		REPORT NUMBER		
University of Michigan				
Dept. of Mechanical Eng	-			
2031 Lay Automotive La				
Ann Arbor, MI 48109-21				
9. SPONSORING / MONITORING A	AGENCY NAME(S) AND ADDRESS(E	s)	10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
AFOSR/NA		1		
801 North Randolph Street				
Room 732		^	004400= 404	
Arlington, VA 22203-1977		//	011203 181	
11. SUPPLEMENTARY NOTES			101 507110	
			CESCIENTIBIC DECEADOU (ACCOUNT	
12a. DISTRIBUTION / AVAILABILIT	TY STATEMENT	: NEFIOR	CESCIENTIFIC RESEARCH (/ TOOP)	DE
12a. DISTRIBUTION / AVAILABILIT		A HATT	ALDIC THIS TECHNO DISTRIBUTION CO	DE
	TY STATEMENT ase; distribution is unlimited	TO HAM?	ALDTIC THIS TECHNIC DISTRIBUTION COLUMN AND LIPPROVED FOR PUBLICATION FOR	DE
		TO HAM?	ALDIC THIS TECHNO DISTRIBUTION CO	DE
Approved for public relea	ase; distribution is unlimited	TO HAM?	ALDTIC THIS TECHNIC DISTRIBUTION COLUMN AND LIPPROVED FOR PUBLICATION FOR	DE
	ase; distribution is unlimited	TO HAM?	ALDTIC THIS TECHNIC DISTRIBUTION COLUMN AND LIPPROVED FOR PUBLICATION FOR	DE
Approved for public releases	ase; distribution is unlimited	O BANY EWE	ALDTIC THIS TECHNIC DISTRIBUTION COLUMN AND BURNES OF PUBLIC SERVING MATTER.	DE
Approved for public releases 13. ABSTRACT (Maximum The behavior of liquid to the second seco	ase; distribution is unlimited um 200 Words) fuel sprays was studied by di	rect numerical simu	ALDTIC THIS TECHNIC DISTRIBUTION COLUMN AND APPROVED FOR PUBLIC BEST OF BUILDING BUI	DE
Approved for public release 13. ABSTRACT (Maximum The behavior of liquid to dimensional simulation)	ase; distribution is unlimited um 200 Words) fuel sprays was studied by dis were used to determine both	rect numerical simu	ALDTIC THIS TECHNIC DISTRIBUTION COLUMNISTS THE PROVED FOR PUBLIC AS EXPRESSION IS UNITED. Lations. Two- and three-rops and their interaction with	DE
Approved for public release 13. ABSTRACT (Maximum The behavior of liquid to dimensional simulation the ambient flow. The N	ase; distribution is unlimited um 200 Words) fuel sprays was studied by di s were used to determine bot Navier-Stokes equations were	rect numerical simuth the formation of description of description and the solved by a finite of	Lations. Two- and three-rops and their interaction with lifference/front tracking	DE
Approved for public release 13. ABSTRACT (Maximum of Liquid to the ambient flow. The National technique that allowed to the ambient allowed to the ambient flow.	ase; distribution is unlimited am 200 Words) fuel sprays was studied by di s were used to determine bot Navier-Stokes equations were resolution of inertial and vise	rect numerical simuth the formation of de solved by a finite occurs forces as well a	Lations. Two- and three-rops and their interaction with lifference/front tracking s the inclusion of surface	DE
Approved for public release 13. ABSTRACT (Maximum The behavior of liquid to dimensional simulation the ambient flow. The National technique that allowed to tension at the deformab	ase; distribution is unlimited um 200 Words) fuel sprays was studied by dis were used to determine both avier-Stokes equations were resolution of inertial and vise le boundary between the fue	rect numerical simuth the formation of de solved by a finite cous forces as well a l and the air. To exa	lations. Two- and three-rops and their interaction with lifference/front tracking s the inclusion of surface mine the primary atomization	DE
Approved for public release 13. ABSTRACT (Maximum of Liquid to the deformation of Liquid to the ambient flow. The Maximum of the technique that allowed the tension at the deformation of dression of dression of dression of the deformation of dression of the deformation of dression and the formation of dression at the deformation of dression and the formation of dression and the deformation of dression at the deformation of dression at the deformation of dression and the deformation of dression at the deformation at the deformati	fuel sprays was studied by disk were used to determine both vavier-Stokes equations were resolution of inertial and vise le boundary between the fuelops, several simulations of the	rect numerical simuth the formation of de solved by a finite cous forces as well a l and the air. To exane breakup of sheare	lations. Two- and three-rops and their interaction with lifference/front tracking s the inclusion of surface mine the primary atomization d immiscible interfaces have	DE
Approved for public release 13. ABSTRACT (Maximum of liquid to dimensional simulation the ambient flow. The National technique that allowed tension at the deformable and the formation of dressed done. Two-dimensional release the statement of t	ase; distribution is unlimited arm 200 Words) fuel sprays was studied by dis were used to determine both Navier-Stokes equations were resolution of inertial and vise le boundary between the fue ops, several simulations of the sional simulations were used	rect numerical simuth the formation of de solved by a finite cous forces as well at and the air. To exame breakup of sheare to examine the initial	lations. Two- and three-rops and their interaction with lifference/front tracking s the inclusion of surface mine the primary atomization d immiscible interfaces have all breakup and to establish the	DE
Approved for public release 13. ABSTRACT (Maximum of Liquid of Examples of Examples of Liquid of Examples of	fuel sprays was studied by dis were used to determine both avier-Stokes equations were resolution of inertial and vise le boundary between the fue ops, several simulations of the sional simulations were used solution. A three-dimensional	rect numerical simulation of de solved by a finite de cous forces as well all and the air. To exame breakup of sheare to examine the initial code using cylindrical	lations. Two- and three-rops and their interaction with lifference/front tracking s the inclusion of surface mine the primary atomization d immiscible interfaces have all breakup and to establish the ical coordinates and local grid	DE
Approved for public release 13. ABSTRACT (Maximus The behavior of liquid to dimensional simulation the ambient flow. The National technique that allowed tension at the deformab and the formation of drobeen done. Two-dimension recessary numerical respectively.	fuel sprays was studied by disk were used to determine both varier-Stokes equations were resolution of inertial and vise le boundary between the fuelops, several simulations of the sional simulations were used to examine how the initial	rect numerical simuth the formation of de solved by a finite cous forces as well at and the air. To exame breakup of sheare to examine the initial code using cylindrativo-dimensional in	lations. Two- and three-rops and their interaction with lifference/front tracking s the inclusion of surface mine the primary atomization d immiscible interfaces have all breakup and to establish the	DE
Approved for public release 13. ABSTRACT (Maximus The behavior of liquid to dimensional simulation the ambient flow. The National technique that allowed tension at the deformab and the formation of drobeen done. Two-dimension recessary numerical respectively.	fuel sprays was studied by dis were used to determine both avier-Stokes equations were resolution of inertial and vise le boundary between the fue ops, several simulations of the sional simulations were used solution. A three-dimensional	rect numerical simuth the formation of de solved by a finite cous forces as well at and the air. To exame breakup of sheare to examine the initial code using cylindrativo-dimensional in	lations. Two- and three-rops and their interaction with lifference/front tracking s the inclusion of surface mine the primary atomization d immiscible interfaces have all breakup and to establish the ical coordinates and local grid	DE
Approved for public release 13. ABSTRACT (Maximus The behavior of liquid to dimensional simulation the ambient flow. The National technique that allowed tension at the deformab and the formation of drobeen done. Two-dimension recessary numerical respectively.	fuel sprays was studied by disk were used to determine both varier-Stokes equations were resolution of inertial and vise le boundary between the fuelops, several simulations of the sional simulations were used to examine how the initial	rect numerical simuth the formation of de solved by a finite cous forces as well at and the air. To exame breakup of sheare to examine the initial code using cylindrativo-dimensional in	lations. Two- and three-rops and their interaction with lifference/front tracking s the inclusion of surface mine the primary atomization d immiscible interfaces have all breakup and to establish the ical coordinates and local grid	DE
Approved for public release 13. ABSTRACT (Maximum of liquid to dimensional simulation the ambient flow. The necessary numerical respective refinement has been used dimensional "fiber" that	fuel sprays was studied by disk were used to determine both varier-Stokes equations were resolution of inertial and vise le boundary between the fuelops, several simulations of the sional simulations were used to examine how the initial	rect numerical simuth the formation of de solved by a finite cous forces as well at and the air. To exame breakup of sheare to examine the initial code using cylindrativo-dimensional in	lations. Two- and three- rops and their interaction with lifference/front tracking s the inclusion of surface mine the primary atomization d immiscible interfaces have al breakup and to establish the lical coordinates and local grid stability becomes a fully three-	DE
Approved for public release 13. ABSTRACT (Maximus The behavior of liquid to dimensional simulation the ambient flow. The National technique that allowed tension at the deformab and the formation of drobeen done. Two-dimension recessary numerical respectively.	fuel sprays was studied by disk were used to determine both varier-Stokes equations were resolution of inertial and vise le boundary between the fuelops, several simulations of the sional simulations were used to examine how the initial	rect numerical simuth the formation of de solved by a finite cous forces as well at and the air. To exame breakup of sheare to examine the initial code using cylindrativo-dimensional in	lations. Two- and three-rops and their interaction with lifference/front tracking s the inclusion of surface mine the primary atomization d immiscible interfaces have all breakup and to establish the ical coordinates and local grid	DE
Approved for public release 13. ABSTRACT (Maximum of the behavior of liquid to dimensional simulation the ambient flow. The National technique that allowed tension at the deformable and the formation of dresponding the dimensional technique that allowed tension at the deformable and the formation of dresponding the formation of dresponding tensional ten	fuel sprays was studied by dis were used to determine both avier-Stokes equations were resolution of inertial and vise le boundary between the fue tops, several simulations of the sional simulations were used solution. A three-dimensional ed to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventual simulations were used to examine how the initial the eventual simulations were used to eventually breaks up into design and the sional simulations were used to eventually breaks up into design and the sional simulations were used to eventually breaks up into design and the sional simulations were used to eventually breaks up into design and the sional simulations were used to eventually breaks up into design and the sional simulations were used to eventually breaks up into design and the sional si	rect numerical simuth the formation of de solved by a finite cous forces as well at and the air. To exame breakup of sheare to examine the initial code using cylindrativo-dimensional in	lations. Two- and three- rops and their interaction with lifference/front tracking s the inclusion of surface mine the primary atomization d immiscible interfaces have al breakup and to establish the lical coordinates and local grid stability becomes a fully three-	DE
Approved for public release 13. ABSTRACT (Maximus The behavior of liquid to dimensional simulation the ambient flow. The National technique that allowed to tension at the deformable and the formation of droubeen done. Two-dimensional mecessary numerical respectively refinement has been used dimensional "fiber" that the subject terms 14. Subject terms Atomization, Spray, General contents and the formation of drouble statement has been used dimensional "fiber" that the subject terms	fuel sprays was studied by dis were used to determine both avier-Stokes equations were resolution of inertial and vise le boundary between the fue tops, several simulations of the sional simulations were used solution. A three-dimensional ed to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventually breaks up into design and the sional simulations were used to examine how the initial the eventual simulations were used to examine how the initial the eventual simulations were used to eventually breaks up into design and the sional simulations were used to eventually breaks up into design and the sional simulations were used to eventually breaks up into design and the sional simulations were used to eventually breaks up into design and the sional simulations were used to eventually breaks up into design and the sional simulations were used to eventually breaks up into design and the sional si	rect numerical simuth the formation of de solved by a finite cous forces as well at and the air. To exame breakup of sheare to examine the initial code using cylindrativo-dimensional in	lations. Two- and three- rops and their interaction with lifference/front tracking s the inclusion of surface mine the primary atomization d immiscible interfaces have al breakup and to establish the leal coordinates and local grid stability becomes a fully three- 15. NUMBER OF PAGES 3 16. PRICE CODE CATION 20. LIMITATION OF	DE
Approved for public release 13. ABSTRACT (Maximum of the behavior of liquid to dimensional simulation the ambient flow. The National technique that allowed tension at the deformable and the formation of dresponding the dimensional technique that allowed tension at the deformable and the formation of dresponding the formation of dresponding tensional ten	fuel sprays was studied by dis were used to determine both Navier-Stokes equations were resolution of inertial and visible boundary between the fuel tops, several simulations of the sional simulations were used solution. A three-dimensional ed to examine how the initial the eventually breaks up into detail at of the distribution of drops.	rect numerical simuth the formation of de solved by a finite cous forces as well at and the air. To exame breakup of sheare to examine the initial code using cylindrativo-dimensional in rops.	lations. Two- and three- rops and their interaction with lifference/front tracking s the inclusion of surface mine the primary atomization d immiscible interfaces have al breakup and to establish the lical coordinates and local grid stability becomes a fully three- 15. NUMBER OF PAGES 3 16. PRICE CODE CATION 20. LIMITATION OF ABSTRACT	DE

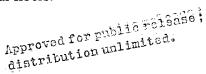
Unclassified NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. Z39-18 298-102

Final Report F49620-00-1-0124 F49620-97-1-0525

The AASERT grant has supported the Ph.D. studies of Mr. Warren Tauber. Mr. Tauber is an excellent student and has done very well in his classes. He has given talks about his research at several meetings and co-authored one paper describing his results. Other papers are in preparation. However, Mr. Tauber has, suffered from health problems that have slowed down his progress. He seems to be over that now and did defended his thesis on September 7th 2001. The dissertation committee was unanimously in their opinion that Mr. Tauber had completed enough work to satisfy the degree requirement and he is currently writing his dissertation (funded as a teaching assistant).

Mr. Warren Tauber studies have focused on the atomization of a jet using direct numerical simulations using a front-tracking technique. Both two-dimensional and three-dimensional simulations of the Kelvin-Helmholtz instability of a small pie-shaped section of the jet are discussed. Unlike the Kelvin-Helmholtz instability for miscible fluids, where the sheared interface evolves into well-defined concentrate vortices if the Reynolds number is high enough, the presence of surface tension leads to the generation of folds that run parallel to the jet. While the initial growth rate is well predicted by inviscid theory, once the Reynolds numbers are sufficiently high, the large amplitude behavior is strongly affected by viscosity. Twodimensional simulations were used to examine the initial breakup and to establish the necessary numerical resolution. A three-dimensional code using cylindrical coordinates and local grid refinement has been used to examine how the initial two-dimensional instability becomes a fully three-dimensional. These simulations have shown that initially axisymmetric waves on a jet will develop into narrow fingers that run parallel to the jet and eventually break into drops by a capillary instability. The axisymmetric waves are driven by the high shear between the jet and the ambient fluid. Eventually, viscous dissipation and separation of vorticity increases the thickness of the shear layer. The local shear becomes weaker and surface tension stops the waves from growing further. Three-dimensionality sets in as the axisymmetric waves start to retreat. Even though "fiber" breakup of jets takes place at relatively high Reynolds number, viscous effects appear to be critical for the generation of three-dimensional fibers.



The work has been described in the following journal papers:

- W. Tauber; G. Tryggvason. Direct Numerical Simulations of Primary Breakup. *Computational Fluid Dynamics Journal*. vol.9 no.1, April 2000.
- W. Tauber, S.O. Unverdi, and G. Tryggvason. The nonlinear behavior of a sheared immiscible fluid interface. Submitted to *Phys. Fluids*
- W. Tauber and G. Tryggvason. Numerical Studies of Primary Atomization. Submitter to the International Journal of Multiphase Flow.